

GUNSHOT WOUNDS TO THE CHEST

Lillian Beate Holmen



Prosjektoppgave ved det medisinske fakultet

UNIVERSITETET I OSLO

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ABSTRACT

Introduction: This is a review of gunshot wounds to the chest. Although uncommon in Norway, they represent a big health problem in other parts of the world and in war situations.

Method: A systematic literature search using PubMed and McMaster+.

Results: Gunshot wounds to the chest can be highly lethal. Depending on the injured organ, a large percentage of the patients die before reaching the hospital.

There is a big difference between low-velocity and high-velocity weapons. Low velocity injuries are most common in the civilian sector, whereas high-velocity injuries are over-represented in war zones and cause much greater tissue damage.

The initial evaluation at the hospital needs to be quick and well practiced in order to rush the most critical patients to treatment and surgery without delay.

All organs in the thoracic cavity may potentially be harmed. Parenchymal lung injury is the most common and the usual form of presentation is hemo- or pneumohemothorax. The most common forms of presentation of cardiac injury are cardiac tamponade and excessive hemorrhage.

However, most patients with gunshot wounds to the chest can be managed non-operatively, or with a simple chest drain.

Conclusion: Gunshot wounds to the chest are dangerous injuries. In order to decrease mortality, good systems for transportation and experienced personnel are necessary.

INTRODUCTION

I was inspired to write about gunshot wounds by the events that took place in Oslo city center and at Utøya the 22nd of July, 2011. Seventy-seven people were killed, 8 by the explosion in the government building and 69 people were shot to death at Utøya. This day that shook our country - and the rest of the world - to the core will be remembered by all for a very long time.

Other than that however, Norway is fortunately a country where gunshot violence is a rarity. According to Statistisk Sentralbyrå (SSB) only 35 people were killed in Norway on average each year from 2001 to 2010. In 2011 the number rose to 114, mostly because of the unfortunate events at Utøya the 22nd of July, but in 2012 the number was at a mere 27 – the lowest in 20 years(1)., Only an average of 18,2% of all these murders were by gun shots(2). Unlike many other countries in the world Norwegian surgeons get little experience with gunshot wounds.

This is different in many other countries like for instance the United States: In 2011 32,163 deaths resulting from firearms were reported, of which roughly 1/3 were homicides and 2/3

were suicides. In addition the estimated number of non-fatal firearm injuries was 73,883(3). There are probably hospitals in big metropolitan areas that see gunshot wounds every single day.

The countries in the world that see the most gunshot violence though, are the countries ravaged by war and dispute. The rate of firearm injuries increases exponentially, both for the military and for the civilians. In addition, the firearms used are not the same type as are usually found in civilian areas. High-velocity injury dominates in war zones, whereas low-velocity injury from handguns is more the usual in times of peace.

I limited my topic to gunshot wounds of the chest, because this is such an interesting part of the body. Many vital organs reside in the thoracic cavity and no gunshot wound to the chest is alike. If the bullet hits the heart or a great vessel you can bleed out in seconds, whereas if it hits another part of the chest, surgery may not even be necessary.

METHOD

I performed a systematic literature search. My search was mostly on PubMed. Initially I searched with different combinations of the terms “gunshot”, “wound”, “injury”, “chest” and “thoracic”. As this resulted in only a few relevant articles, I added the terms “penetrating injury”, “trauma” and “velocity” to the search. I also searched on McMaster+ with the same terms and found one guideline about penetrating injuries to the chest. Because gunshot wounds are a rarity in Norway, the articles are based on experience in other countries of the world, mainly the United States and South Africa, as well as some articles from war zones.

The most relevant articles were selected based on their title. I read the abstract and subsequently did another selection based on its relevance.

Mainly only recent articles were used, but in some cases I included older articles about gunshot wounds in general, for instance, describing mechanisms of injury. Statistics or guidelines from the older articles were not included as their value might be expired.

Additionally I looked up some articles I found on the reference list of previously selected articles when I found them relevant and necessary. I also performed individual searches based on loopholes in my knowledge when needed, mainly the description of certain surgical procedures or the principles of kinetics. In those cases I searched for the individual terms on PubMed, like “damage control” or “laparotomy” and selected the articles based on the relevance of the abstract.

I ordered two special articles through the library, but there were still some articles that might have been relevant and interesting that I was unable to get my hands on.

I focused mostly on low-velocity gunshot wounds, simply because I found more literature on the subject. Whenever high-velocity injuries are discussed, it is specifically mentioned in the text.

RESULTS

Prevalence and statistics

Penetrating chest trauma is a common injury in most American inner-city trauma centers. At LA County & University of Southern California Medical Center for instance, penetrating chest trauma constitutes 7 % of all trauma admissions (4). It is unknown what percentage of these admissions are gunshot wounds.

Injury to the thorax directly accounts for about 25 % of all trauma-related deaths and is a contributing factor in another 25 %. Early mortality is usually due to hemorrhage, catastrophic injury and associated head or abdominal trauma, whereas late mortality most often is a result of sepsis and organ failure. With penetrating injuries, mortality is more often related to vascular injury and shock than in blunt trauma (5).

A retrospective South African study from 2006 reviewed the files of 2019 patients with penetrating chest injury over 32 months. Of these patients only 61 patients had to undergo thoracic surgery for non-mediastinal injury, of which there were 35 gunshot wounds (GSW). The mortality rate for GSWs was 16 / 35 (45,7 %). This rate only includes the patients who were operated on. The article does not mention how many GSWs there were in total. The study found that GSWs were more likely to result in death than stab wounds with a relative risk (RR) of 11,9. This means that patients with GSWs were 11,9 times as likely to die as patients with stab wounds. Thoracoabdominal injury more often resulted in death than chest injury alone with a RR of 4,8 (6).

The same study showed that injury to the lung parenchyma was the most common (68,6 %) followed by injury to the intercostal artery (14,3 %), lung hilum (11,4 %), internal mammary artery (11,4 %) and diaphragm (22,9 %). However, most GSW patients had more than one anatomical site of injury (6).

Another South African study based on the same patient population and the same time period reviewed the cases of penetrating cardiac injuries. One hundred and seventeen out of the total 2019 trauma patients presented with penetrating trauma to the heart, of which there were 21 GSWs with a mortality of 81 %. This is significantly higher than the mortality rate of non-mediastinal injury (7).

Yet another South African study from 2011, found an overall mortality for gunshot wounds to the chest to be 52 %. During a 3 year period 124 patients with GSW's to the chest were admitted to the surgical services in Pietermaritzburg, and during the same period 135 persons with GSW's to the chest were taken to the mortuary (8).

Gun violence is still a big problem in South Africa, however, there has been a reduction of cases since the transition to democracy in 1994 (69 cases per year in 1994 versus 39 cases per year in 2006). In other parts of the world, like Europe for instance, the incidence of penetrating trauma is increasing (7).

In the United States (U.S.), the most common cardiac injuries still originate from blunt trauma from motor vehicle accidents or low-velocity stab wounds. However, during military conflict high-velocity injuries, including GSWs are relatively more common. High-velocity GSWs generally have a higher mortality than low-velocity GSWs. A Turkish study from 1998 reviewed 755 patients with penetrating thoracic trauma over a 6 year period. 54,7 % of the patients had gunshot wounds, and 56,2 % of these were high-velocity injuries. The overall mortality due to firearms in this study was 8,95 %. However, the mortality due to low-velocity GSWs was a mere 2,87 % whereas the mortality due to high-velocity GSW's was 11,6(10).

The reason for the relatively low mortality rate due to GSW's in this series was possibly that most of the patients were relatively stable when admitted., The critically unstable patients died in the field due to lack of a proper transport system that could bring the patients to the hospital quickly.

Principles of kinetics and mechanism of injury

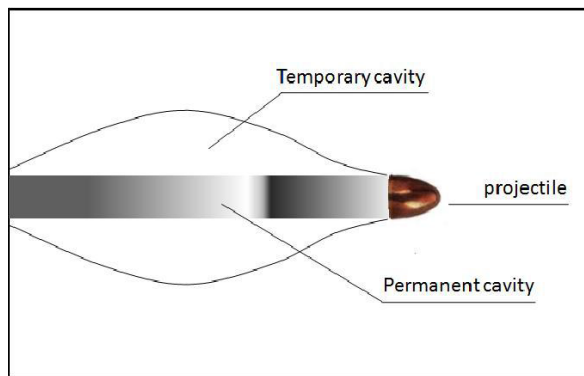
The severity of penetrating chest trauma depends on the weapon used and the energy involved. Small-caliber handgun injuries are characterized by much less primary tissue destruction than wounds caused by hunting or military weapons(10).

To understand this, the law of kinetic energy is important in penetrating trauma. It is as follows: $E = \frac{1}{2} MV^2$ where E represents the energy, M is the mass and V is the velocity. This means that the velocity of the penetrating object is a more important component of the injury than the object size (11). It is usual to divide in three groups:

- Very low energy: caused by knife or stab wound
- Low energy: Attributed to projectiles with muzzle velocity of less than 600 m/s, typically caused by handguns and so logically more common in the civilian population (12).
- High energy: Muzzle velocity of more than 600 m/s, caused by military or hunting weapons (12).

Bullets have an available kinetic energy of 1500-3000 joules (J) for military rifles, 300 – 500 J for handguns and 10 – 15 J for some fragment devices (11). The energy lacerates, contuses and displaces body tissues in certain patterns. For low energy injuries, the energy is confined to the track of projectile where the tissue is crushed by the bullet or fragment. For high energy injuries however, there is a radial injury around the track of the projectile (shock waves) with a temporary cavity where contaminants can be widely dispersed(11). After the projectile passes, there is a transient displacement of the tissue laterally which can reach up to the 40-fold diameter of the bullet (12). Depending on the elasticity of the tissue, it may be pushed aside and then rebound, like skeletal muscle, blood vessels and skin, or break, like bone.

Figure 1: The mechanism of cavitation can cause tissue destruction along the bullet diameter (12).



The consequence of the law of kinetics is that gunshot wounds have a less predictable pattern than for instance stab wounds. The trajectory of a missile may not follow a straight course (13).

A little paragraph about shotgun wounds:
(14)

As an instrument of close range combat, the shotgun has no parallel. At short distances, its destructive capacity is equal to that seen from high-velocity missile injury.

Some terms:

The gauge reflects the number of lead balls weighing a total of 1 pound that will fit in a bore of specific diameter. In general, the larger the gauge, the smaller the bore diameter.

The choke is the narrowing in the distal bore diameter usually 1-6 inches from the muzzle. Choke determines the shot density delivered to a target area of 30 inches (75 cm) at 40 yards (35 m). It ranges from full choke (65 – 75 %), modified choke (45 – 55 %), improved cylinder (35 – 45%) to cylinder (25 – 35%).

3 types of shotgun ammunition are commonly used: birdshot, buckshot and slugs, with increasing wounding capacity. Shotgun slugs are quite devastating because of the great kinetic energy being transferred to the victim. In addition, they are often rifled, which causes the slug to rotate on its long axis in flight, which gives them a greater accuracy. The distance from the muzzle is another important factor in shotgun injuries. Blast injury shotgun wounds (< 3 yards) have tremendous wounding potential and are equivalent to high-velocity wounds. Since shotgun pellets rarely exit the body, all of this kinetic energy is transferred to the victim. Shotgun wounds from a distance of 3-7 yards usually damage structures deep to the deep fascia, whereas wounds from a distance over 7 yards usually are contained within the subcutaneous tissue and deep fascia.

Initial evaluation and diagnostics

Most authors agree more or less on the initial evaluation. Obviously, it depends on the clinical condition of the patient. A short history is critical. It is usually provided by the pre-hospital personnel and should include the mechanism of injury, the time from injury, vital signs and neurological status at the scene as well as any changes during transport(5).

Next comes a short physical examination based on the globally applied ABC-method: Airway, Breathing and Circulation. The first step is to determine if there is a need for tracheal

intubation, unless this has already been done by the prehospital personnel on the scene. However it is important to be aware that intubation can exacerbate hypotension and cause cardiovascular collapse in patients with pericardial tamponade or tension pneumothorax, because of the increased intrathoracic pressure caused by positive pressure ventilation, which reduces venous return (13).

The second step is to inspect the chest wall for inconsistencies in appearance or chest rise, auscultation of breath sounds, palpation of the chest wall and inspection of the trachea to look for midline deviation (13). A tension pneumothorax should be suspected if there are decreased breath sounds on one side of the chest and tracheal deviation. (7).

The 3rd step is to start infusion of crystalloid fluids through large intravenous cannulae.

A tube thoracostomy can be placed in the Emergency Room if indicated, and the patient is then transferred to the clinic or the operating room according to their clinical status (10).

The patients can be roughly divided into 3 groups: Patients in cardiac arrest or imminent cardiac arrest; patients with severe hypotension or cardiac tamponade, but who are not in immediate danger of cardiac arrest; patients in a fairly stable condition and patients with a benign presentation.

The lifeless / critically unstable patient

If the patient is lifeless on arrival, or critically unstable with imminent cardiac arrest, some authors advocate for an Emergency Room resuscitative thoracotomy without any investigations. (4, 7, 14), but not all hospitals or trauma centers have the necessary training, skills or capacity for this kind of procedure and will therefore always take the patient directly to the operating room.

Degiannis et al.. stated that an emergency room thoracotomy was not indicated if the vital signs were absent for more than five minutes before arrival to the emergency room (7). However, Demetriades and Velmahos were more liberal even if the patient suffered a loss of vital signs in the field. They had three reasons: The time-line may be unreliable in such a hectic situation, there is always the possibility of organ donation, and it is an excellent way to drill the medical and nursing staff (4). They found a survival rate of 4,4 % for emergency room thoracotomy in patients with gunshot wounds to the chest.

The hypotensive patient

Patients with severe hypotension, but who are not in immediate danger of cardiac arrest, should have an emergent operation in the operating room, often without specific investigations. All the articles I read agreed on this point. Demetriades and Velmahos state that in cases of multiple GSWs, a trauma ultrasound, as well as a chest and abdominal X-ray, can be useful if readily available in the emergency room in order to determine the source of the hypotension(4). A portable chest radiograph may provide rapid information about the pleural space, such as a pneumothorax which may require a tube thoracostomy (5).

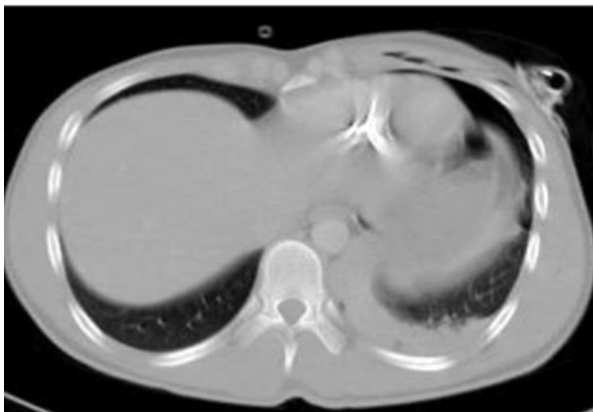
Volume infusion is an important part of the treatment of GSW victims, since they generally experience a great blood loss. However, if there are signs of cardiac tamponade, one should restrict the volume administered before operation (8).

The signs of cardiac tamponade are hypotension, increased central venous pressure and muffled heart sound. However, all the signs are rarely present in a trauma situation. Most authors agree on the use of FAST (Focused Abdominal Sonogram for Trauma) to diagnose cardiac tamponade, (4, 5, 7-9, 13) but not all have the available technology. Additionally, FAST can accurately detect pneumothorax, hemothorax and peritoneal fluid, and thereby it can be useful to determine management priorities (13).

The hemodynamically stable patient

If the patient is fairly stable, or the hypotension can be easily corrected with intravenous fluids, the patient should be further evaluated. This is in order to identify contained vascular injuries, aerodigestive and diaphragmatic injuries and other life-threatening conditions (4).

The fact is, surgical intervention is not always required. In many cases a chest drain or merely observation is sufficient. Demetriades and Velmahos found that about 60 % of the patients with transmediastinal GSW's that are hemodynamically stable on admission can be managed non-operatively. On the other hand, transmediastinal gunshot wounds are associated with a high incidence of severe injuries to vital intrathoracic structures, so most patients are dead on admission or in severe shock. (4)



Further investigations include chest radiograph, hemodynamic monitoring, electrocardiography and most importantly a CT scan for more detailed and organ specific information (5, 8). However Dominiguez and co. found that the differentiation between mediastinal, pericardial and myocardial injury was frequently limited by metallic streak artifact in a war setting with mainly high velocity injuries (9). (see picture below)

Figure 2: Chest CT of a patient with an isolated GSW to the left chest wall. It demonstrates the retained fragment within the cardiac silhouette, but limiting artifact does not allow for determination of effect on myocardium(9)

In spite of this, CT is increasingly recognized as a tool to assess the trajectory of a bullet (6, 12) and to select patients that need further investigation, such as angiography, esophagography and endoscopy (4). (See pictures below(4))

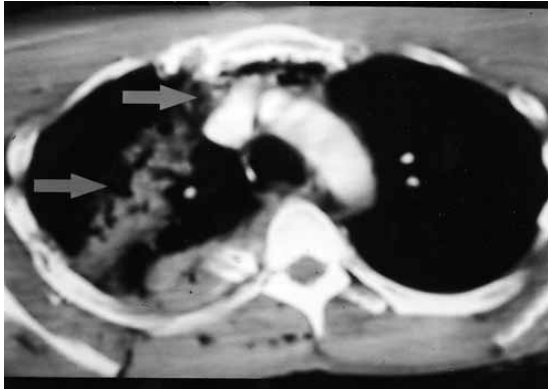


Figure 3: Mediastinal gunshot wound with a bullet trajectory near the aorta. This patient needs an aortography

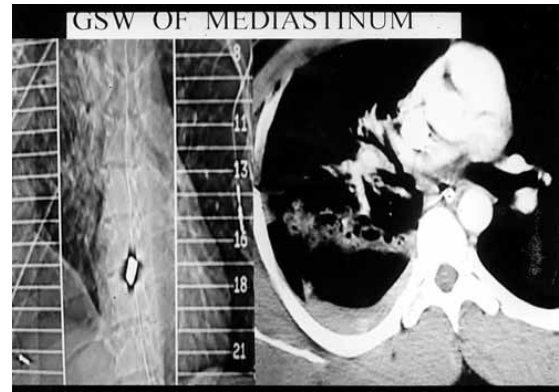


Figure 4: Mediastinal gunshot wound with trajectory away from the major vessels and the aerodigestive tract. No angiography or esophageal studies are required.

The indications for operation among the hemodynamically stable patients are relatively consistent and the most commonly used criteria are:

- Initial blood loss of 1000-1500 ml in the thoracostomy tube (4-6, 8)
- Ongoing bleeding of > 200 ml per hour for 4 hours (4-6)
- Persistent air leaks following mediastinal trauma (4-6)
- endoscopically or radiographically proven tracheal-bronchial injury or esophageal injury (4, 6)
- radiographic evidence of great vessel injury (4, 6, 15)

Clarke et al. point out, however, that chest drain output alone is not a reliable sign, as the chest tube may be blocked by a clot or badly positioned. It must be interpreted together with the overall clinical picture (8). Regular interval chest radiographs can also be of help in assessing whether the chest tube is functioning properly (5).

I would like to include a little paragraph on thoracoabdominal injuries, as it is not rare for GSW victims to have multiple sites of injury. It is important to know that diaphragmatic injuries may be asymptomatic. If untreated, they may cause late diaphragmatic hernias. Demetriades and Velmahos found that in 31% of proven diaphragmatic injuries there were no signs of peritonitis and in 40% the chest film was normal! So it has become part of their protocol to evaluate laparoscopically all patients with left thoracoabdominal or anterior right thoracoabdominal injuries even if there are no sign of diaphragmatic injury, (4)

SPECIFIC ORGANS

Lungs

Pneumothorax:

A pneumothorax is a very common injury concerning both blunt and penetrating trauma to the chest, and occurs in the great majority of patients with transpleural penetrating chest injuries (13). The clinical image can vary enormously: from cardiovascular collapse with a tension pneumothorax to no symptoms at all.

Development of a tension pneumothorax is potentially lethal and must be dealt with immediately. The alarm signs are shock, distended neck veins and unilaterally absent breath sounds, and the treatment is a needle decompression. A large bore needle is inserted in the 2nd intercostal space in the midclavicular line, which converts it into a simple pneumothorax. The definitive treatment for a pneumothorax is a chest tube in the 5th or 6th intercostal space in the anterior axillary line in order to evacuate the air and re-expand the lung. O'Connor and Adamski found that there is an associated hemothorax in 20% of the cases, therefore they recommend a large bore chest tube (5).

They also found a complication rate of 6 – 36 % with the major complications being empyema, improper tube placement, parenchymal lung injury, undrained effusion and hemothorax.

Hemothorax

Gunshot injuries to the chest are associated in 34 % to 36 % with hemato- or hemato-pneumothorax (16). A hemothorax is an accumulation of blood in the pleural cavity.

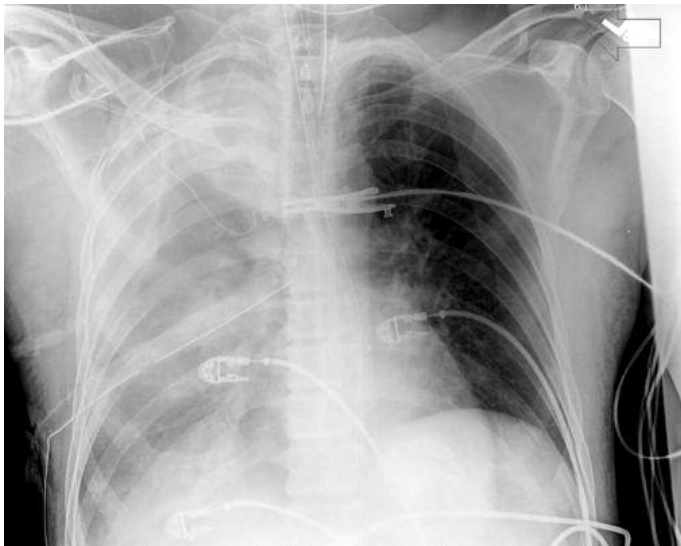


Figure 5: Chest radiography with a large right haemothorax. Endotracheal tube and tube thoracostomy are seen.

The symptoms vary from shortness of breath and chest pain to signs of hemorrhagic shock. Although most are venous in origin and stop spontaneously, bleeding from great vessels or other arteries may occur. In these cases rapid intervention is necessary to control the bleeding and to prevent a tension effect. Clake et al. found that injury to the lung parenchyma was the most common source of bleeding, followed by the internal thoracic or the intercostal vessels (8).

One should always suspect a hemothorax when a patient has a GSW to the chest. The suspicion should be increased by the

symptomatology and physical findings and can be confirmed by a , although some use bedside ultrasound to diagnose. A chest X-ray can detect as little as 150 to 200 ml of blood (5).

The treatment is a thoracostomy tube. One should check the output regularly, as a massive bleeding would indicate the need for surgery to repair the wound. As noted before, a decreased output does not necessarily mean that the bleeding has stopped; it could simply be because a clot is blocking the chest drain or a suboptimal position of the drain. O'Connor and Adamski therefore recommend repeated chest X-rays to assess whether or not surgery is necessary. A CT scan can also be a useful tool, as it can confirm the presence and size of a residual hemothorax and it can detect an active bleeding. A residual hemothorax may be a source for infection or fibrosis with lung entrapment and respiratory compromise (4). In addition, it is important to know that the hemothorax becomes more organized and fibrotic the longer it exists, so the need for operation increases if it isn't detected early. In their study though, O'Connor and Adamski reported that thoracotomy was required in less than 15 % of the cases. This is probably due to the low-pressure vascular system and rich concentration of thromboplastin in the lungs, which leads to the bleeding usually being self-controlled (4).

Keel and Meyer reported in 2007, that there is an increasing detection of both hemothorax and pneumothorax with the increasing use of CT instead of the conventional chest X-ray (17). They noted that occult pneumo- and hemothoraces were detected in many patients with a normal chest X-ray on subsequent CT in several studies. This is beneficial, because some may need and benefit from a chest tube.

Pulmonary contusion:



Figure 6: Large right upper lobe pulmonary contusion from a gunshot wound.

Pulmonary contusion is much more common in blunt than in penetrating trauma, but it is quite common with the use of high-velocity weapons, because of the shock wave created on impact (13).

The clinical image varies considerably, from clinically silent to respiratory compromise in need of mechanical ventilation.

The mechanism is as follows: Energy is transmitted to the lung tissue resulting in hemorrhage, cell and tissue damage, and edema. In many cases this leads to hypoxia and respiratory distress. (5, 13)

The treatment consists of analgesia for associated rib fractures, early mobilization, chest physiotherapy and

judicious fluid administration. Only the most severe cases require intubation and mechanical ventilation.

Heart:

In 1987, Godwin and Tolentino found that most patients (60-81 %) with a penetrating injury to the heart die before reaching the hospital (18). It is one of the most dramatic injuries sustained by a bullet.

A bullet, particularly a high velocity one, often destroys the tissue adjacent to its path. Thus the bullet doesn't necessarily have to pass through the heart to damage it, it can pass nearby and still do harm. Debridement may therefore be necessary as part of the repair of gunshot injuries (18).

The two most common modes of presentation of cardiac injury are cardiac tamponade and excessive hemorrhage (7, 18). Which modality depends on the size of the wound in the pericardium, as a small wound lets only a small amount of blood escape the pericardial space and can easily be closed by a blood clot, resulting in tamponade (18), whereas a large wound does enough damage to the pericardium that the blood is not contained, resulting in rapid exsanguination. It is worth noting though, that bullets usually cause a more jagged tearing of the myocardium (as opposed to stab wounds) resulting in myocardial hemorrhage more often than cardiac tamponade (9). Godwin and Tolentino noted that only 20 % of GSWs result in tamponade, as opposed to 80-90 % of stab wounds. This can be of some importance in explaining the differences in mortality seen in stab wounds and GSWs to the heart.

Cardiac tamponade:

As little as 60-200 ml of blood is enough to cause tamponade, because the pericardial sac cannot distend acutely (18).

The clinical findings are: hypotension, elevated central venous pressure, distended neck veins, muffled heart sounds and pulsus paradoxus. Godwin and Tolentino noted that these findings were present in less than half of the patients in most series. Ultrasound is used in most cases to make a diagnosis. Pericardiocentesis, draining the pericardium with a long needle, is effective in an acute setting, however the blood is often clotted, so surgical decompression of the pericardium and repair of the cardiac wound are required (18).

Cardiac tamponade may save the life of the patient. It does so by preventing exsanguination. However, cardiac tamponade has its own morbidities. Blood accumulates in the pericardial sac, causing the diastolic pressure to rise and venous return and cardiac output to diminish. This again leads to a reduction in coronary artery flow, subendocardial hemorrhage and arrhythmia. Cardiac arrest may result.

Injury to the chambers of the heart:

The anatomy of the heart determines the likelihood of chamber injury. The right ventricle is most commonly injured due to its anterior position in the chest, followed by the left ventricle

(13). In a prospective study from 1998, Asensio et al. found that the right ventricle was injured in 43 % of the cases of penetrating cardiac injury, the left ventricle in 33 % of the cases, the right atrium in 14 % and the left atrium in only 5 % (19). It is relevant though, that bullets usually damage more than one chamber (18) and injury to the heart should be considered in any patient with a penetrating wound to the chest, neck, upper abdomen or back.

In rare cases, the bullet may injure the coronary arteries (in about 4 %), the septum (about 1 %) or a cardiac valve. The last is extremely rare in hospital-based studies, partly because most die before they reach the hospital (18).

If the bullet gets lodged in a cardiac chamber, it will most likely embolize, or a clot forming around it will embolize. Emboli from the right heart pass to the pulmonary arteries and emboli from the left heart pass to a systemic artery, usually the lower extremity, but sometimes to the head if the clot is small. Sometimes a bullet that is lodged in the myocardium can remain encysted or calcified in the muscle. This may lead to conduction disturbances (18).

Other injuries

Injury to the great vessels:

Injuries to the great vessels of the thorax are very uncommon in hospital-based studies as only minor injuries are compatible with survival (20). Most of these patients die in the field due to rapid exsanguination. Demetriades and Velmahos found thoracic great vessel injury in 5 % of the GSW cases (4). Clarke et al found the same number (8). Vascular injury can present as massive hemothorax in need of immediate operative intervention and decompression (13). Most of the patients that reach the hospital alive are in severe shock.

Injuries to the descending aorta are more common than to the ascending. If the injury is in the intrapericardial part of the aorta, it can cause hemopericardium and cardiac tamponade, and if the injury is elsewhere, it presents as hemothorax (18). Injuries to the aorta are particularly devastating, because several factors predispose to hemorrhage: the relative thinness of the aortic wall, the high intra-luminal pressure and the absence of tough surrounding tissue to stop the bleeding. A clot may temporarily prevent exsanguination, thereby allowing the patient to reach the hospital alive, but subsequent lysis of the clot may lead to massive hemorrhage. Since the patient is in shock in most of the cases, there is rarely time for any imaging or further studies before rushing to the operating room, but a chest X-ray may show mediastinal widening and hemothorax.

Demetriades and Velmahos described a mortality of over 90 % for thoracic aortic injuries and 65 % for subclavian vascular injuries (4).

Injury to the vena cava is more common in the abdominal inferior part than in the superior part. Because of the thin walls of the vena cava, hemostasis is prevented. In addition, associated organ or vascular injury is probable, which leads to a high mortality - the higher

the site of injury, the greater the mortality (18). As with aortic injuries, there is rarely time for imaging and a chest X-ray is rarely helpful in any case.

Thoracic duct injury:

Thoracic duct injury is uncommon in trauma, but it may cause increased mortality and morbidity if left untreated. It may be associated with great vessel injury or vertebral body fractures. The diagnosis is suspected when milky white chest drainage is seen in the chest tube and is confirmed if the drain effluent contains more than 110 mg / dl triglycerides and more than 3 grams of protein. The treatment is a low-fat diet and pleural drainage. If the chylothorax is persistent, surgical ligation may be necessary (5).

Injury to the chest wall and bony structures:

Rib fractures is the most common chest injury in trauma, but logically enough, it is encountered more often in blunt force trauma than in penetrating trauma (5, 17). However, a bullet may hit a rib hard enough for it to break, and high energy shotguns and other high energy weapons can cause significant bony and soft tissue damage that may affect the stability of the chest wall causing respiratory problems (13).

Rib fractures are often associated with other chest injuries, such as pneumothorax, hemothorax, pulmonary contusion and flail chest. Although not usually lethal in itself, the pain from the fractures may have a negative impact on the pulmonary function. It can lead to increased atelectasis, the inability to clear secretions and hypoventilation. It is therefore commonly advised to be aggressive with the pain control, especially if there are other injuries present (13, 17).

Flail chest is the compromised integrity of the thoracic cage with three or more rib fractures in two or more places (17). This unstable section of chest wall exhibits paradoxical motion. The abnormal motion however, can be difficult to detect which makes the diagnosis difficult (21). Flail chest is often associated with pulmonary contusion. It is considered to be a serious injury with increased mortality. Stabilization of the segment with manual or object pressure is no longer recommended, as it restricts chest wall expansion and thereby interferes with proper respiratory mechanisms. Patients in severe respiratory distress require endotracheal intubation and mechanical ventilation.

Injuries to the tracheobronchial tree, esophagus and diaphragm:

Injuries to the tracheobronchial tree are less common than in blunt trauma and generally involve the cervical trachea. Early signs and symptoms are nonspecific, which means that the injury often goes unrecognized until it develops into a tracheobronchial fistula, mediastinitis or empyema. (13) Late signs of tracheal injury are subcutaneous emphysema, hemoptysis,

change in phonation and dyspnea (5). It is very important to secure the airway; a flexible bronchoscopy can be of assistance during intubation.

Injury to the esophagus is also difficult to detect, for three reasons: It is uncommon; there are no specific clinical signs and no specific chest X-ray findings (13). It can lead to dangerous complications, and is highly lethal if diagnosis is delayed (5). This is why it is recommended to do further diagnostic test of both esophagus and tracheobronchial tree whenever there is a penetrating trauma that is suspected to cross the mediastinum. A combination of CT, contrast esophagram and esophagoscopy will diagnose all esophageal injuries.

GSWs to the lower chest often involve the diaphragm (13). Murray and Demetriades found that 59 % of thoracoabdominal gunshot wounds resulted in diaphragmatic injury (22). This is important to detect, as it can lead to late diaphragmatic hernias if untreated.

Infections of the thorax:

Despite the high temperature when they are fired, bullets are shown to be non-sterile (23). However, as much as 50 % of bullet fragments may be left unextracted without developing secondary infection,, possibly because metallic foreign bodies do not readily serve as site for infection and they have a low inflammatory potential (24).

War wounds have historically had a higher infection potential than civilian injuries, because of the high velocity weapons, the contaminated wound environment and the delay to definitive surgery compared with civilian low velocity injuries (25).

Petersen and Waterman described some of the problems of patients with high-energy penetrating trauma (11): The patient has massive bleeding which leads to ischemia and decreased leukocyte and antimicrobial delivery to affected tissues. In addition, the patient often needs multiple transfusions, which effectively removes his / her circulating immunity. All these factors can contribute to the development of an infection.

There is a general consensus that high energy gunshot injuries requires intravenous antibiotic treatment (11, 12, 14), but prophylactic antibiotics in low energy injuries is controversial and depends on the surgeon's preference (12).

Principles of treatment and surgical methods:

Although GSWs to the chest sound very dramatic – which they can be, in some cases – the fact is that most of the patients are treated non-operatively or by chest tube alone (14, 17, 26). Demetriades and Velmahos found that only 15-20 % of the patients with GSWs to the chest required thoracotomy (4).

The usual procedure is that the hemodynamically stable patient goes through a certain amount of examinations to determine the severity of the damages. A chest tube is inserted if there is indication (Pneumo- or hemothorax) and subsequent measures are dependent on the chest tube output. Ahmed and Chung hypothesized in their study from 2010 that this may be

inadequate. The reason they gave were that missed injuries, retained hemothorax, or foreign material may be difficult to address later. They thought that early thoracoscopy should improve the outcome (26).

In order to find an answer, they conducted a retrospective review of 88 patients with penetrating injuries to the chest that were initially treated with a chest tube and had a retained hemothorax beyond 48 hours. Of these patients, 27 went through an early video-assisted thoracoscopy (VATS), where a small camera is introduced into the chest via a scope. Fifty-five patients were in the control group. They either had a single chest tube placed on admission, had their chest tube changed or had several tubes placed. What they found was that early VATS reduced the length of stay, the days in the ICU and the need for open thoracotomy. They further stated some of the limitations of using chest tube alone:

- It does not provide for debridement, hemostasis, clots or foreign body removal
- It routinely misses diaphragmatic defects
- There may be malfunctioning of the chest tube or drainage system, leading to ongoing bleeding being missed
- It may take a few days to realize that something is wrong, after which the appropriate treatment may no longer be optional
- A chest tube manipulation after 48 h of persistent incomplete lung expansion is often ineffective, because a fibrinous clot may have already formed.

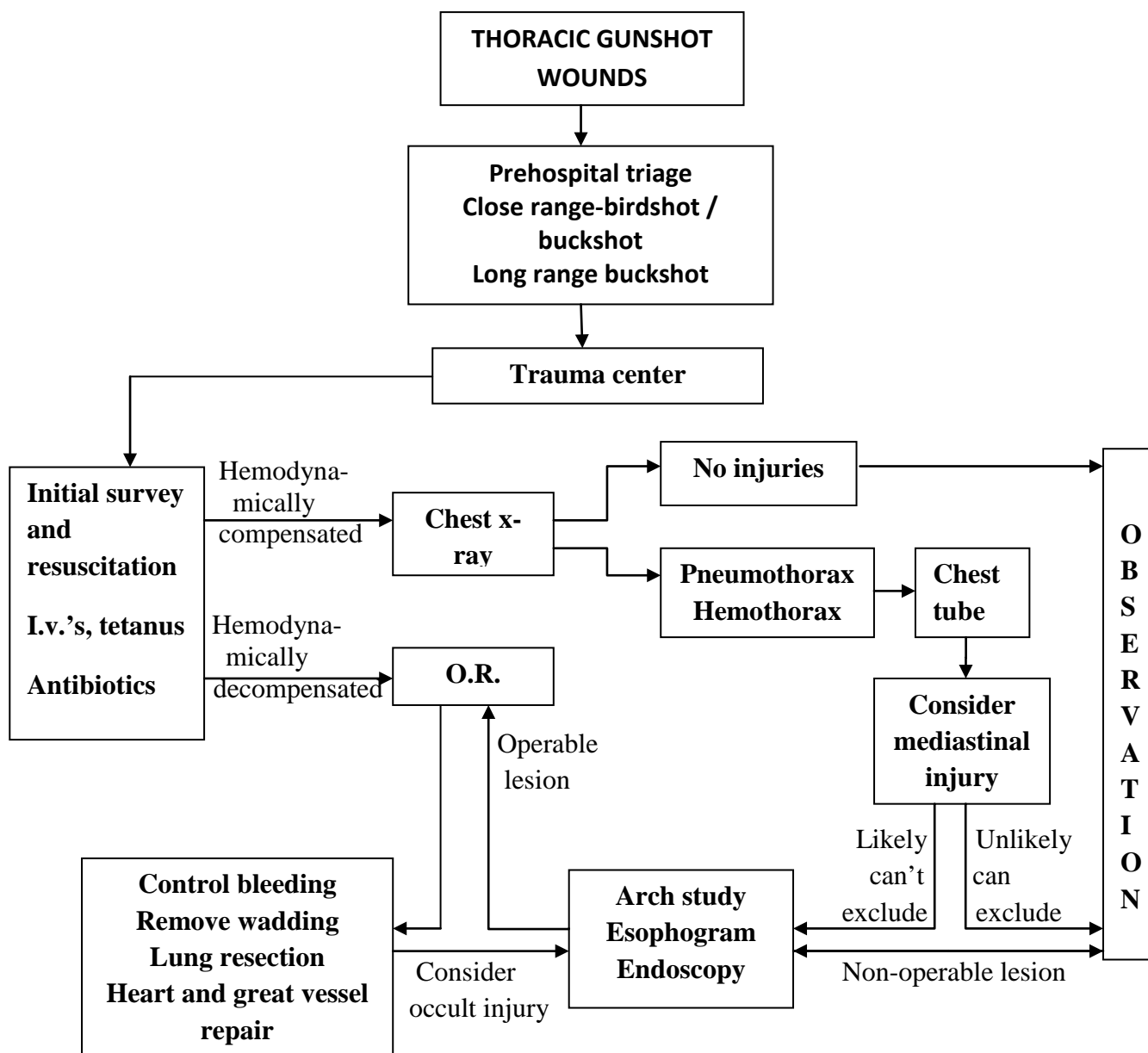
Their conclusion was that early VATS addresses most of the limitations of the chest tube, and has a much higher diagnostic potential. Early VATS has indeed replaced open thoracotomy more and more for the treatment of undrained hemothorax during the last decade (17, 27).

Walker and co. made an algorithm for the management of shotgun wounds in their article from 1990 (14). The basics are that hemodynamically compensated patients can initially be managed with a non-surgical approach. It is mandatory to do a careful assessment for mediastinal injury and if the clinical condition deteriorates, operation is required. The hemodynamically unstable patients on the other hand should be resuscitated if necessary and taken straight to the operating room. The algorithm is attached below. Although this study is outdated, most of the principles remain the same to this day.

METHODS OF INCISION:

There are several different methods of incision and each has its advantages and disadvantages. For instance, patients who are hemodynamically decompensated may not tolerate to be positioned laterally, as it can exacerbate their preexisting hypotension. In addition, the surgeon's knowledge of the extent of the organ damage is often limited, as there is little time for supplementary examination in unstable patients. Chest X-ray may be the only available source of information in these cases, and it tells little of the projectiles path and possible mediastinal involvement (5). This is a lot easier in stable patients, as CT adds valuable information. Below I will give a short description of the most common incision types.

Fig. 7. Algorithm for management of thoracic shotgun wounds(14):



Median sternotomy:

A sternotomy yields rapid exposure to the heart and great vessels, in addition to giving access to both pleural spaces (5, 7, 15). It is suitable for unstable patients. A sternotomy is also versatile, as it can be extended as a laparotomy, periclavicular or a neck incision. Thus it is the incision of choice for any cardiac or mediastinal injury, unless there is a suspicion of severe coexisting thoracic extracardiac injury, or if there is indication for an emergency room thoracotomy (7). For stable patients, a partial sternotomy can be of use (15). Some authors not

familiar with heart surgery do argue that a sternotomy is more difficult to perform and to close than a lateral incision (8).

Thoracotomy:

There are several types of thoracotomies:

- *The antero-lateral thoracotomy* is quick and it can be extended across the midline or onto the abdomen as a laparotomy. It is preferred over the postero-lateral thoracotomy in shocked patients because they have a low tolerance for lateral positioning, as mentioned above. The disadvantage with this incision is that it gives little exposure of the posterior thoracic structures (5) and the access to the aortic arch is limited. It is the incision of choice for urgent surgical access when the surgeon is confident that the anticipated injury can be reached through a unilateral incision (8).
- *The postero-lateral thoracotomy* is the preferred incision for most elective thoracic operations not involving the heart, as it gives optimal exposure of the posterior thoracic structures. The disadvantages are its lack of versatility and its effect on hemodynamically unstable patients.
- *The bilateral anterior thoracotomy* (clamshell incision) is by some authors considered to be the best incision for emergency thoracotomies (28) because it provides the most rapid and definitive access to all thoracic structures for assessment and control.

A relevant note for GSW patients is that they relatively often present with multiple gunshot wounds. In cases of thoracoabdominal injury the surgeon must consider which side of the diaphragm to address first. The general rule is to handle the “cavity of major blood loss first” (7), but the surgeon must be prepared to change strategy if the operative findings do not account for the patient’s condition. If possible one should close the abdominal cavity before exploring the thoracic cavity, and vice versa, in order to prevent contamination. Obviously, in some cases this is not possible.

METHODS OF REPAIR

Pulmonary injuries:

Most pulmonary parenchymal injuries are self-limiting. This is partially due to the low-pressure circuit in the lungs and it is why 80 % of penetrating chest injuries can be managed with a tube thoracostomy (5). Those patients who do require operation usually have more extensive parenchymal damage, more arterial injuries and often present in shock.

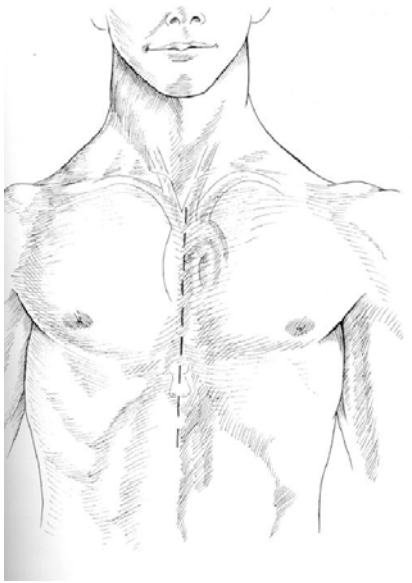


Figure 8 (5): The sternotomy affords excellent exposure to all structures except those in the posterior mediastinum.

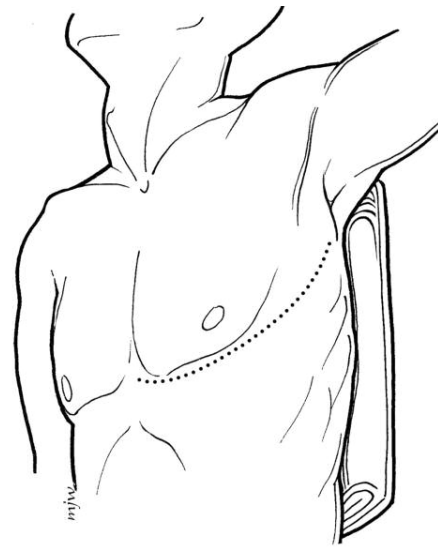


Figure 9 (5): Approach for an antero-lateral thoracotomy. Placing a bump under the back and extending the arm provides improved thoracic exposure.

Most of the parenchymal injuries can be treated successfully by pneumonorrhaphy (suture of the lung), tractotomy or wedge resection and the goal is to create hemostasis and an air tight staple line(5):

- *Wedge resections* are easily done with linear gastrointestinal staplers. It is a means of removing devitalized peripheral lung tissue without resorting to an anatomical resection, where entire anatomical sections (or sometimes lobes) are removed (6, 15). Wedge resections require less technical expertise and they allow a faster, more effective control of the bleeding without losing viable pulmonary parenchyma.
- *With tractotomy*, one limb of a linear stapling device is inserted through the missile track and is fired. This opens the parenchyma along the length of the wound and the individual bleeding vessels and bronchi can be found and suture ligated (5, 6). This is especially useful when the damaged section of the lung is not easily resected. Petrone and Asensio found in 2009 that in fact 85 % of all pulmonary injuries which require operation can be managed successfully with stapled pulmonary tractotomy (27). (See fig. 10)

In their study from 2007, Loogna et al. reported increasing mortality with the increasing complexity of the procedure. They had a mortality of 100 % for pneumonectomy, for instance – the patients died due to exsanguination, pulmonary edema or right heart failure. They thought that careful attention to avoid volume overloading before and during the procedure as well as maintaining a negative fluid balance postoperatively might contribute to survival (6).

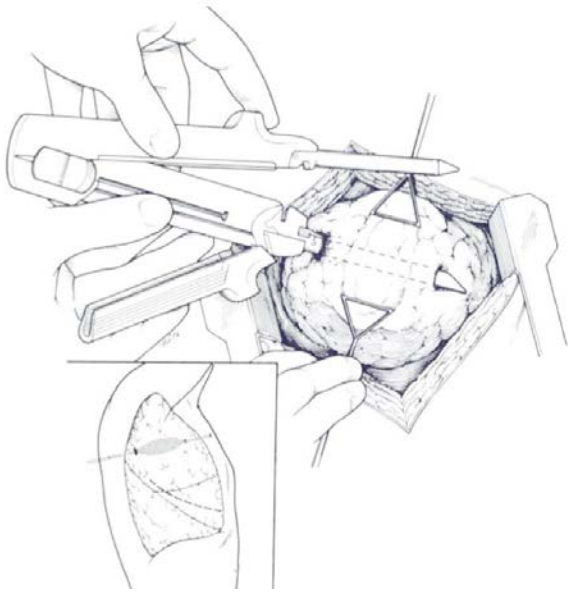


Figure 10: Depicts the cavitory effect created by a missile traversing the lung. Stapling device is placed through the orifices of entry and exit wound

O'Connor and Adamski found a lower mortality for pneumonectomy in their 2010 study, though still very high – close to 80 % (5). As they remark, there are few published series on the subject. In this study pneumonectomy was only indicated for severe pulmonary hilar injury and the causes of death were massive uncontrollable hemorrhage and acute right heart failure.

Common complications related to lung resections are empyema, persistent air leaks, necrotic lung secondary to impaired blood supply and torsion (5).

In high-velocity gunshot victims, severe lung contusion can lead to acute respiratory distress syndrome. Extracorporeal membrane oxygenation is the final rescue for patients with the worst respiratory insufficiency (17).

Vascular damage

Every surgeon has a preferred way to deal with vascular damage. O'Connor and Scalea explained the most common techniques that they used in their paper from 2008 based on 36 patients with penetrating thoracic great vessel injury. Veins were preferentially ligated if the patient was unstable, but if possible they were repaired. Arteries were repaired primarily or using graft interposition (15). Keel and Meyer's report from 2007 indicates that endovascular repair has become the gold standard for aortic injuries (17).

Tracheal injury

Tracheal injury is rare, but challenging to repair. For the cervical trachea, a low collar incision gives the best overview; for distal tracheal and proximal right bronchial injuries a right postero-lateral thoracotomy is most suitable. Left bronchial injuries are best approached through the left chest, though this may be challenging because of the position of the aorta. (5)

The divitalized tissue is debrided and the airway defect is closed without tension using interrupted absorbable sutures. The injury is then buttressed with muscle for additional support (15).

Esophageal injury

Esophageal injury is equally rare, but highly lethal if the diagnosis is delayed. For thoracic esophageal injury, the esophagus is exposed by thoracotomy, the devitalized tissue is debrided and the injury is repaired with a primary two-layer suture, buttressed by vascularized muscle or pleura. Nasogastric and distal enteral feeding tubes are placed (5).

O'Connor and Adamski found a mortality rate of 19 % in 2010, where 50 % of the survivors had complications.

Damage control

Damage control is a philosophy of abbreviated operation used commonly by trauma surgeons in unstable patients (5) and relates to emergency operation to stop excessive bleeding. The procedure has been found to reduce the mortality of unstable patients with penetrating thoracic injuries (17). Once the bleeding is controlled, the resuscitation continues in the intensive care unit and re-exploration is planned after physiological normalization. The resuscitation addresses the so-called "lethal triad": coagulopathy, acidosis and hypothermia (29), which occurs with massive hemorrhage.

Rapid treatment of the coagulopathy is considered central to the outcome and strategies include administration of fresh frozen plasma and platelets; use of recombinant factor VIIa, cryoprecipitate and tranexamic acid; and calcium (29).

Outcome / Prognosis

Gunshot wounds to the chest remain highly lethal with a high pre-hospital mortality. The rates vary in different studies, but some conclusions can be made: GSWs to the chest are generally more lethal than stab wounds to the chest (6, 8, 15); most GSW victims that reach the hospital alive can be managed without surgical intervention, often a chest drain is sufficient (6); and the patients who need surgery have a relatively high mortality. The mortality depends on several factors, including the injured organ, the type of weapon used, the number of simultaneous injuries, and the experience and quality of the trauma team..

Loogna et al. found a mortality of 45,7 % for the patients with GSWs to the chest who needed operative intervention for non-mediastinal injury. However, they found that thoracoabdominal GSWs were substantially more lethal than isolated GSWs to the chest, with a relative risk of 4,8 (6). Degiannis et al. found no such distinction concerning GSWs to the heart (7) – probably because this type of injury is so lethal in itself. There is another study though, that supports the hypothesis that several injuries to different sites of the body lead to a higher mortality than injuries to the chest alone: Cooper et al.'s study from 1992 showed that the mortality rate of isolated chest injuries is in the range of 4 % to 12 % but increase to 13 % to

15 % when another system is involved and to 30 % to 35% when two or more systems are involved (30).

Penetrating trauma to the heart is among the most dramatic and lethal of all injuries. In one review of 1198 cases only 6 % arrived at the hospital alive (31)! Degiannis et al. reported of a mortality of 81 % for cardiac gunshot wounds whereas patients with cardiac stab wounds had a mortality of only 15, 6 % (7).

In Clarke's et al. study from 2011 less than a quarter of the patients with a penetrating cardiac injury reached the hospital alive (8). Of those that did and who required surgery, the survival rate was about 90 %. They found an overall mortality for gunshot wounds of the chest of 52% (8).

Another group of patients with a very high mortality are the patients with penetrating injury to the thoracic great vessels. The incidence of thoracic great vessel injury is about 5 % from GSWs (4, 15) and the prehospital mortality is overwhelming. Demetriades and Velmahos found a mortality of over 90 % for thoracic aortic injury and 65 % for subclavian vascular injuries (4).

The third factor to consider - the type of weapon used – was studied by Inci et al. in 1998. They conducted a retrospective study including 755 patients with penetrating thoracic trauma. Of these patients 54,7 % were GSWs and of those again 56,2 % were high velocity injuries. The overall mortality due to firearms was 8,95 %, however the mortality for low-velocity injuries was only 2,87 % whereas the mortality due to high-velocity injuries was 11,6 % (10). Additionally they calculated an injury severity score (ISS) for each patient and evaluated the relation between the ISS and mortality. 17 % of the patients with an ISS > 25 died, whereas only 0,9 % of those with a score < 16 died. The mean ISS was 20,17 (10). The morbidity rate of this study was 23,3 % where the most common complications were septic problems, atelectasis, intrathoracic hematoma and acute respiratory distress syndrome .

DISCUSSION

Wide dispersion in space

The studies I included were from different hospitals in different countries and even different continents, where the conditions and systems vary greatly between different institutions. The Chris Hani Baragwanath Hospital in South Africa is home to the two studies “Emergency thoracic surgery for penetrating, non-mediastinal trauma” and “Penetrating cardiac injuries: recent experiences in South Africa” for instance, did not have access to CT or FAST at the time of the studies (6, 7). This naturally affects the way the patients were evaluated there, and it might even have affected the outcome and results of the study.

Different countries also have different means and routines for transport and on-scene treatment. This has to do with many factors, like the quality of the infrastructure, the training of the pre-hospital personnel (the population density and the distance and time to hospital).

Different hospitals in different countries may have different diagnostic criteria. This is hard to evaluate, since they were practically never described. Thus it is not 100 % certain that the authors are talking about exactly the same injuries all the time. This makes a comparison between the different studies harder and can account for, in part, the different outcomes.

Wide dispersion in time:

Some of the articles are quite old. I tried being selective at the beginning, including as few old studies as possible. However, many of the newer articles used older studies as references and it became natural to use those studies as a basis.

As far as possible, I only used information that was applicable in our time and situation. For some of the information, the time-component is of little importance anyway, like the description of the injuries. It is safe to assume that the same organ-injuries exist now as 20 or 30 years ago, however, they may have a different dispersion depending on the evolution of the weapons used. In addition, most of the surgical techniques we use today have been practiced for many years.

Method discussion:

I could, and some would say should, have calculated a median or mean value for mortality and the different injury types. However, I decided against this, as I felt it would not be of any significance. For the reasons stated above, I doubt that the different hospitals / studies are always comparable and a mean value would just have been a number without meaning. The main points remain clear: Some injuries, like injury to the heart and great vessels have a high mortality whereas injuries to the lung parenchyma are usually less critical and have a lower mortality.

As for my references, I included many that I found on the reference lists of other articles. The fact that these articles did not show up on my initial search is peculiar and may suggest that I have missed some other relevant articles worthy of being included in my study.

Quality of the studies:

For the most part, the studies had a high quality, describing their criteria for inclusion and exclusion, having a large population and explaining the different contexts behind the studies, using many sources to back up their data and including numbers such as Relative Risk (RR) and Confidence Interval (CI).

The main bulk of the studies I used were retrospective studies. Retrospective studies are generally considered to be inferior to prospective studies. In retrospective studies it is difficult to control bias and confounders, they rely on the accuracy of the written record or the recall

of individuals (recall bias), it is difficult to establish cause and effect and the results are, at best, hypothesis generating. However, it would be very difficult to effectuate a randomized clinical trial concerning gunshot wounds, simply because it would not be ethical. There could be lives at risk if you gave one treatment to one group and another treatment to the other. Anyhow, a retrospective study is very practical in a hospital-based setting, because you can use the existing records and it is inexpensive. Additionally it allows study of rare occurrences and it can generate a hypothesis that is subsequently tested prospectively.

Lack of specific studies: Many of the studies I included – the majority in fact – did not speak of gunshot wounds alone. Instead they involved penetrating injuries in general, both stab wounds and gunshot wounds. As much as I tried to use only the information concerning GSWs, this was not always possible. Some of the articles didn't specifically differentiate between the two and sometimes the majority of the patients had suffered stab wounds, making the selection of patients with GSWs quite small. This makes it hard to exclude normal variation as a factor.

However, the principles of surgery, specifically the type of incision and the methods of repair remain the same. The difference is that GSWs generally cause more damage than stab wounds, and so the procedures are more complicated and extensive, accounting for the difference in mortality.

In some cases the incidence and mortality rates are more or less reliable. This is particularly true concerning rare injuries with a high death rate. For instance injuries to the thoracic great vessels: All of the studies agreed that this is rare and very devastating. In fact, most of the patients die in the field. Since the bulk of the studies were hospital based however, these patients were often not included, as they were sent directly to the morgue. The result is that the mortality rates given in some of the studies may be deceptively small, as they only account for the patients that die in the hospital.

CONCLUSION

Gunshot wounds to the chest are a huge problem in some areas of the world and have a relatively high mortality, depending on the damaged organ and the type of weapon used. A large part of the patients die even before they reach the hospital. Those that do reach the hospital though, have a much better survival rate and can mostly be treated conservatively, with observation or a chest tube.

Overall, one thing remains clear: A good outcome depends on rapid transportation and operation! Sadly, penetrating trauma, especially high energy injuries are likely to increase in the future. This is a result of the increasing penetration of military assault weapons in the civilian sector via the illegal narcotics trade and that the fact that mass casualty events, such as acts of terrorism or shootings, are becoming more commonplace (11). For these reasons, all hospitals and trauma centers should establish good routines concerning both low- and high-velocity GSWs. You never know if and when such an event could occur in your home town.

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